Exhibit (how to calibrate)

Flow Meter Calibration

Prepared by Robert George, NMED-GWQB

Definition of Flow Meter Calibration

The Bureau of Reclamation's *Water Measurement Manual* defines calibration as:

"**Calibration** is the process used to check or adjust the output of a measuring device in convenient units of gradations. During calibration, manufacturers also determine robustness of equation forms and coefficients and collect sufficient data to statistically define accuracy performance limits. In the case of long-throated flumes and weirs, calibration can be done by computers using hydraulic theory. Users often do less rigorous calibration of devices in the field to check and help correct for problems of incorrect use and installation of devices or structural settlement. A calibration is no better than the comparison standards used during calibration."

This definition makes clear that calibration is the act of comparing and adjusting a measuring device against a standard. It also highlights that there are different levels of calibration that are performed for different purposes. NMED has proposed that all flow measurement devices be calibrated in-place, under actual operating conditions (field calibration) to within ± 10% of the actual flow. Calibrations are required following the installation of a device, repair of a device and annually thereafter. This proposal fits the latter description of calibration from the definition above, which is a calibration performed by users to a less rigorous standard for the purposes of checking and correcting problems with newly installed or repair devices or for devices that have been affected over the course of time. It is not intended to require a rigorous field calibration to determine the maximum accuracy that a manufactured device is capable of achieving in a particular setting, which NMED recognizes would be overly time-consuming, difficult and costly.

The Need for Flow Meter Equipment Field Calibration

The need for field flow meter equipment calibration is not obvious to some. Devices are frequently sold with statements that no calibration is required in order to achieve a stated accuracy, provided the device is installed and maintained in accordance with specific requirements. In the case of an ideal installation, this statement may be true. However, what is not considered is that: (1) most installation situations require compromise which leads to less that ideal installation conditions, (2) there are a wide variety of errors that can contribute to inaccuracy and these often go unidentified, and; (3) degradation tends to affect the accuracy of all installations over time in a manner that cannot be predicted. <u>Without field calibration of flow measurement devices, NMED has no way of determining that gross inaccuracy of a flow measurement device does not exist.</u> To this

EXHIBIT
tabbies
3224-5

end, NMED is less concerned with absolute precision than with verifying that measurements are reasonably accurate and repeatable over time.

Definition of Terms Related to Calibration Accuracy
(Adapted from the Bureau of Reclamation's Water Measurement Manual)

Precision is the ability to produce the same value within given accuracy bounds when successive readings of a specific quantity are measured. Precision represents the maximum departure of all readings from the mean value of the readings. Thus, a measurement cannot be more accurate than the inherent precision of the combined primary and secondary device precision.

Error is the deviation of a measurement, observation, or calculation from the truth. The deviation can be small and inherent in the structure and functioning of the system and be within the bounds or limits specified. Lack of care and mistakes during fabrication, installation, and use can often cause large errors well outside expected performance bounds. Since the true value is seldom known, some investigators prefer to use the term uncertainty.

Spurious errors are commonly caused by accident, resulting in false data. Misreading and intermittent mechanical malfunction can cause discharge readings well outside of expected random statistical distribution about the mean. A hurried operator might incorrectly measure discharge on a staff gauge. Spurious errors can be minimized by good supervision, maintenance, inspection, and training. Experienced, well-trained operators are more likely to recognize readings that are significantly out of the expected range of deviation. Unexpected blockages of flow in the approach or in the device itself can cause spurious errors. Repeating measurements does not provide any information on spurious error unless repetitions occur before and after the introduction of the error. On a statistical basis, spurious errors confound evaluation of accuracy performance.

Systematic errors are errors that persist and cannot be considered entirely random. Systematic errors are caused by deviations from standard device dimensions. Systematic errors cannot be detected by repeated measurements. They usually cause persistent error on one side of the true value. For example, error in determining the crest elevation for setting staff or recorder chart gage zeros relative to actual elevation of a weir crest causes systematic error. The error for this case can be corrected when discovered by adjusting to accurate dimensional measurements. Worn, broken, and defective flow meter parts, such as a permanently deformed, over-stretched spring, can cause systematic errors. This kind of systematic error is corrected by maintenance or replacement of parts or the entire meter. Fabrication error comes from dimensional deviation of fabrication or construction allowed because of limited ability to exactly reproduce important standard dimensions that govern pressure or heads in measuring devices. Allowable tolerances produce small systematic errors which should be specified.

Calibration equations can have systematic errors, depending on the quality of their derivation and selection of form. Equation errors are introduced by selection of equation forms that usually only approximate calibration data. These errors can be reduced by finding better equations or by using more than one equation to cover specific ranges of measurement. In some cases, tables and plotted curves are the only way to present calibration data.

Random errors are caused by such things as the estimating required between the smallest division on a head measurement device and water surface waves at a head measuring device. Loose linkages between parts of flow meters provide room for random movement of parts relative to each other, causing subsequent random output errors. Repeating readings decreases average random error by a factor of the square root of the number of readings.

Total error of a measurement is the result of systematic and random errors caused by component parts and factors related to the entire system. Sometimes, error limits of all component factors are well known. In this case, total limits of simpler systems can be determined by computation. In more complicated cases, different investigators may not agree on how to combine the limits. In this case, only a thorough calibration of the entire system as a unit will resolve the difference. In any case, it is better to do error analysis with data where entire system parts are operating simultaneously and compare discharge measurement against an adequate discharge comparison standard.

Comparison standards for water measurement are systems or devices capable of measuring discharge to within limits at least equal to the desired limits for the device being calibrated. Outside of the functioning capability of the primary and secondary elements, the quality of the comparison standard governs the quality of calibration.

Discrepancy is simply the difference of two measurements of the same quantity. Even if measured in two different ways, discrepancy does not indicate error with any confidence unless the accuracy capability of one of the measurement techniques is fully known and can be considered a working standard or better.

Flow Measurement Device Field Calibration

NMED is seeking to have initial and routine calibrations performed on flow measurement devices under actual operating conditions (field calibrations). Field calibrations of this type are to be performed by individuals knowledgeable in flow measurement and in the installation/operation of the particular device. As mentioned before, this type of calibration is performed for the purposes of checking and correcting problems with newly installed or repaired devices or for devices that may have been affected over the course of time and is recognized to be held to a less rigorous standard than a full characterization of a device to it maximum accuracy. NMED is proposing that accuracy of flow measuring devices be maintained to within ± 10% of the comparison standard discharge (actual flow). The acceptable level of accuracy to be attained by the comparison standard discharge is at least equal to that of the allowable error of the device being calibrated (± 10%). The comparison standard is accepted to be "actual flow" but understood to contain some (undetermined) systematic and random level of error, although reasonable efforts should be made to minimize both. Spurious errors in establishing the comparison standard are to be largely avoided by careful oversight.

Typically during field calibration, the measurement output of the flow measurement device is evaluated at a stable discharge rate against the comparison standard. The discrepancy between the indicated discharge for the device and the actual flow (as determined by the comparison standard) is use to calculate percent of error (offset) as follows:

$$E\%Q_{Cs} = \frac{100(Q_{Ind} - Q_{Cs})}{Q_{Cs}}$$

Where:

Q_{Ind} = *indicated discharge from device output*
Q_{Cs} = *comparison standard discharge concurrently measured in a more precise way*
$E\%QCs$= *offset error in percent of comparison standard discharge*

The level of error detected during the calibration represents the positive or negative offset of the device from the actual flow. Technically, this is not a statistically appropriate representation of the measurement error of the device, because no attempt at characterizing the accuracy of the calibration standard or of the discrepancy of the output of the device from the calibration standard throughout the measurement range (zero, mid-range and full scale) is made. Additionally, the level of inaccuracy allowable (± 10%) is not defined in terms of scale (zero, mid-range, full scale), so ±10% is potentially acceptable at any range. However, because NMED is less concerned with absolute precision than with attaining a reasonable accuracy and a reasonable degree of repeatability, this level of calibration measurement is sufficient for this purpose. More sophisticated statistical analysis of the accuracy of a measurement device will be accepted by NMED, provided it follows accepted principals for calibration.

If the offset of the device is beyond the bounds of ± 10% of the calibration standard, adjustment of the device to bring it within these bounds is appropriate and should be attempted and the calibration rechecked. If the device shows a high level of inaccuracy beyond these bounds, displays an inability to repeat a measurement (within the same bounds), or calibration to within ± 10% cannot be attained, a faulty device or non-standard installation may be indicated and more in-depth investigation and device repair/replacement may be warranted.

Calibration of Hydraulic Structure Primary Measuring Devices

Hydraulic structure primary measuring devices are capable of accuracies of varying degree, dependent upon the device type and the range that it is operating in (scale) compared with its design range (full scale). Virtually all hydraulic structure primary measuring devices are capable of accuracies within ± 10% when installed in accordance with the specific requirements for each unique device. Beneficially, under most circumstances, the errors that can adversely affect the accuracy of hydraulic structure primary measuring devices are relatively limited and easy to detect. Should a hydraulic structure be installed improperly or damaged in place, problems with its operation can be readily identified by visual inspection (provided the inspector has an understanding of the function of the particular structure type). Once identified, most problems are easily corrected. Put simply, this class of device is fairly easy to install in a manner that will produce reasonably accurate results and the causes of inaccuracy are readily indentified.

Because of these two characteristics, hydraulic structure primary measuring devices, when installed correctly, constitute a suitable comparison standard discharge (in and of themselves) which can therefore be used to represent "actual flow" for the purposes of calibrating secondary devices (head sensing, readout and totalizers). For this reason, NMED is not seeking field calibration of *standard* hydraulic structure primary measuring devices. The ability to act as a calibration standard and the inherit simplicity of these devices, accounts for their widespread use throughout the water supply, wastewater treatment and agricultural industries.

Calibration of Head Sensing, Readout and Totalizing Secondary Devices

In the case of head sensing, readout and totalizing equipment, initial and routine calibration/adjustment by comparison to the hydraulic structure primary measuring device is necessary to ensure that accurate flow measurements are first established and then maintained. NMED is proposing that calibrations be performed initially and then annually thereafter. When an initial or routine calibration is performed, the degree of inaccuracy (positive or negative offset) is characterized in relation to the flow in the hydraulic structure primary device.

Calibration of Commercial Velocity Sensing Meters

Commercial meters are sold with the device's stated accuracy clearly identified. Many meters claim that the device is sold pre-calibrated and that no field (sometimes referred to as "wet") calibration is needed. Some of the newest velocity sensing meters do allow diagnostics of the primary device elements (e.g. mag-meters often have the ability to self check their magnetic field characteristics), but they do not provide a suitable comparison standard discharge in and of themselves. Furthermore, what is not typically clear is that any deviation from the laboratory conditions under which the device was calibrated can result in inaccuracy. For example; the application of a device that was calibrated on clean water to measuring wastewater with a high concentration of suspended solids could greatly affect accuracy. Unexpected (or detected) turbulence induced prior to a meter can result in very different performance than during calibration conditions. The length of pipe prior to and after a meter, the pipe material and even the roughness of the interior surface of the pipe can affect accuracy. The incident angle that a device is mounted at can affect accuracy and function. In fact, a great number of systematic, random and spurious errors can contribute to inaccuracies in real world conditions. Worse, these errors are generally not readily observable or measurable in closed-pipe systems and therefore not easily detected. NMED has no way of ensuring that closed-pipe flow measurement devices have been installed and are operating completely within the manufacturer's requirements, and therefore capable of accurate flow measurement. For this reason, field calibration of the primary and secondary elements of commercial closed-pipe velocity sensing meters is critical.

The selection of a suitable comparison standard discharge for the field calibration of commercial velocity sensing meters requires skill and knowledge about flow measurement. NMED is seeking to have individuals knowledgeable in flow measurements with the particular device in use develop and perform field calibrations. Examples of the type of comparison standard discharges that could be utilized for field commercial meter calibrations include:

- Volume/time comparison, where a known volume of liquid moves through the meter in a known amount of time. For example, the liquid level in a sump of known dimensions is measured before and after a pump moves liquid from the sump and through the meter over a five minute interval. By calculating the volume of liquid pumped in five minutes, a comparison standard discharge can be established. The totalized meter reading discrepancy from the actual flow for the five minute interval can be determined and the meter offset calculated. Errors of measurement and timing must be controlled.
- A standard hydraulic device primary measuring structure, such as an orifice plate can be inserted in the pipe metered by the device in question. Head readings taken at standard locations before and after the orifice plate can be used to determine the discharge (using an equation or table specific for the orifice plate) and the discharge can be used as a comparison standard discharge. Care must be taken in the centering of the orifice plate and in the head readings. The method can typically only be employed on wastewater for short calibration durations due to plugging at the head measurement locations.
- A standard hydraulic structure primary measuring device, such as a weir or flume can be constructed at the outlet of the discharge stream so that the actual discharge can be determined from the weir or flume for comparison by the close-pipe measuring device output.

NMED acknowledges that field calibration of commercial in-pipe meters can be difficult to accomplish under many circumstances but contends that field calibrations are necessary to eliminate gross inaccuracies of flow measurements at dairy facilities. NMED is seeking to have field calibration procedures outlined by dairy facilities (as opposed to requiring specific approaches) to allow the use of the least expensive, most easily accomplished procedure for a given facility. NMED is proposing that calibration procedures be performed by individuals with experience in flow measurement and the use of the particular device in question. NMED anticipates that a variety of calibration methods will be used, as applicable in various settings.

Flow Meter Calibration Reports

NMED is proposing to have dairy facilities submit a flow meter calibration report annually to demonstrate that flow measurements are achieving the required level of accuracy. The reports are required to contain an identification of the flow meter consistent with the Discharge Permit, the location of the meter, the method of flow meter calibration employed (assumed to be a narrative description), the measured accuracy of the meter before and after adjustment and a list of any repairs made to the meter in the previous year.

The report is to be submitted in the facility's monitoring report due by May 1 of each year.

References

United States Department of the Interior, Bureau of Reclamation, *Water Measurement Manual*, Revised Reprint 2001, available at:
http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/

United States Department of the Interior, Environmental Protection Agency, NPDES Compliance Inspection Manual, Chapter 6, Flow Measurement, available at:
http://www.epa.gov/compliance/resources/publications/monitoring/cwa/inspections/npdesinspect/npdesmanual.html